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The relationship between blood flow, oxygen consumption and blood oxygen levels during transient local activation of the cerebral cortex

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Transient activation of a region of the brain cortex results in an increase in the local rate of oxygen consumption, and stimulates an increase in blood flow to the stimulated region, a phenomenon known as neurovascular coupling. Under normal conditions, the relative increase in blood flow during activation is observed to exceed the relative increase in oxygen consumption, by a factor $n > 1$. As a consequence, the oxygen content of blood in the stimulated region increases. The associated change in hemoglobin saturation forms the basis for the blood oxygen level dependent (BOLD) signal detected during functional magnetic resonance imaging (fMRI) of the brain. Despite the extensive use of this technique, its physiological basis is incompletely understood. While MRI techniques allow simultaneous observations of local cerebral blood flow (CBF) and the BOLD signal, oxygen consumption rate cannot be measured with similar spatial and temporal resolution. Here, a Krogh-cylinder-type theoretical model was used to analyze the relationship between blood flow, oxygen consumption and hemoglobin saturation during transient activation of rat somatosensory cortex. The equations for time-dependent convection and diffusion of oxygen in the blood and tissue were solved using the finite-element method. Experimental data [1] on variation in blood flow and hemoglobin saturation were used to deduce parameters describing the time-dependent variation in oxygen consumption rate. The value of n was found to be approximately 3, consistent with observations in other experimental models. Experimental BOLD signals show a brief initial dip in hemoglobin saturation at the start of activation, although this is not consistently observed. In the simulations, such an initial dip was predicted and shown to be sensitive to the timing of the increase in flow relative to the increase in consumption. This theoretical model provides a method for deducing time-varying oxygen consumption rate from BOLD fMRI observations of the locally stimulated cerebral cortex. Such data can be used to investigate the dynamical characteristics of neurovascular coupling.

[1] Masamoto *et al.*, *NeuroImage* 40:442, 2008

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